Multi-deal Negotiation

Blue Sky Ideas Track

Tim Baarslag
Centrum Wiskunde & Informatica
Amsterdam, The Netherlands
T.Baarslag@cwi.nl

ABSTRACT

Negotiating multiple deals is an essential day-to-day activity for many businesses. Procurement, for instance, typically represents one of the largest expense items for businesses worldwide. Today, 95% of European businesses are still negotiating their goods and services entirely unaided by computers, which has been shown to lead to significantly less efficient outcomes, increased costs, and highly labor-intensive processes. Enabling the automation of general-purpose multi-deal negotiations would therefore have an enormous impact on the competitiveness and profitability of businesses world-wide. However, currently available algorithms are not yet capable of performing multiple complex and interdependent negotiations at the same time. This so far underexplored research challenge calls for solutions and methods beyond the state-of-the-art research in auctions, game theory, or bilateral negotiation. It requires new asynchronous negotiation strategies that can reach multiple interdependent deals, as well as novel mathematical coordination mechanisms that are able to steer pro-actively toward a desirable aggregate outcome.

The challenges of multi-deal negotiation call for 1) a mathematical model and protocol for multi-deal negotiation algorithms that can strike multiple partial deals with multiple partners; 2) coordination techniques for making optimal trade-offs regarding expected agreement utility; and 3) multi-deal negotiation strategies that can provide online probability estimates of the expected outcome. Altogether, such a research endeavor would deliver the fundamental underpinnings for general-purpose multi-deal negotiation algorithms, thereby paving the way for future systems for domains ranging from procurement and energy to ethics and transportation.

KEYWORDS

Negotiation; Multiple deals; Procurement; Interdependent strategies; Coordination

ACM Reference Format:

Tim Baarslag. 2024. Multi-deal Negotiation: Blue Sky Ideas Track. In *Proc. of the 23rd International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2024), Auckland, New Zealand, May 6 – 10, 2024*, IFAAMAS, 6 pages.

Proc. of the 23rd International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2024), N. Alechina, V. Dignum, M. Dastani, J.S. Sichman (eds.), May 6 – 10, 2024, Auckland, New Zealand.

1 INTRODUCTION

Negotiation of multiple deals is an essential day-to-day activity for many businesses. Magazine publishers, for example, require different amounts of ink on an ongoing basis and must negotiate continually with their suppliers. These negotiations usually involve multiple, concurrent deals that are each struck bilaterally: i.e. they tend to happen through private channels with each supplier, where complex multi-issue agreements are struck not just about amounts of ink, but also about the price, delivery time, and so on. Importantly, all these negotiations influence and overlap each other: what cannot be obtained in one negotiation needs to be secured in another one. A magazine publisher must therefore maneuver carefully to get a good outcome in each negotiation, but also needs to ensure that each deal is in line with the overall requirements. As a result, these interactions create a complex coordination problem involving the dynamic alignment of multiple negotiations.

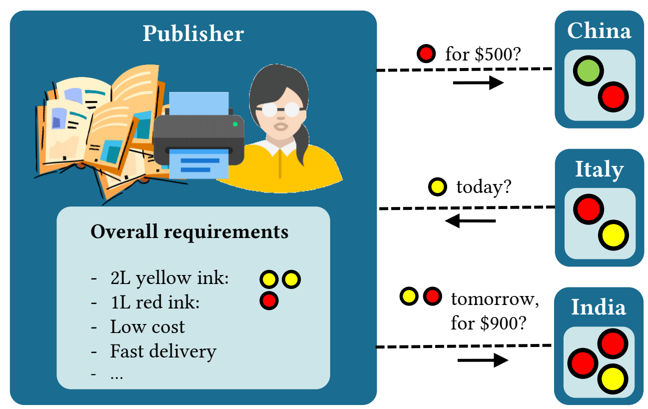
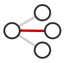
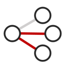


Figure 1: An example of the challenges of multi-deal negotiation for a magazine publisher: securing multiple partial deals, while aligning them with the overall requirements.

The complicated and time-consuming nature of negotiating goods or services (i.e. *procurement*) means that few firms truly know and understand how much they spend, on which products, and with which suppliers [3]. This presents a big problem to businesses as procurement usually represents one of the largest expense items in a firm's cost structure [3]. Automated negotiation research has shown early indications that electronic negotiations can lead to cost savings and strategic advantages [72] and can even outperform physical negotiations with up to 70% better outcomes [46, 66]. Improving the computationally intensive task of procurement is therefore one of the great promises of computerized negotiation,

Table 1: Related research in negotiation, organized by the number of issues under negotiation (single/multi) and the deals that can be struck (single/multi).

			Single-issue	Multi-issue
 **Single deal**		***Mediated protocol***	*Auction / game theory* [1, 19, 32]	*Combinatorial auction* [35–37, 51]
		Bilateral negotiation	*Bargaining* [26, 27, 43]	*Bilateral multi-issue negotiation* [23, 25, 31, 33, 34, 47, 75]
		Multiple negotiations	*Best price negotiation* [45]	*Single multi-issue negotiation* [42, 48, 58, 63, 70, 71]
 **Multi-deal**		***Multiple negotiations***	*Best aggregate price negotiation* [16, 18, 67]	*(underexplored)*

with enormous potential impact on a firm's competitiveness and profitability [62].

However, state-of-the-art negotiation algorithms are not yet capable of performing several complex and interconnected negotiations at the same time. The reason for this gap [66] is that rather than enabling multiple negotiations, most of the negotiation research is focused on a single bilateral negotiation or, when multiple negotiations are concerned, negotiators typically need to obtain only one deal (e.g. finding the cheapest seller).

The aim of this paper is to suggest lines of attack in tackling the open challenge of developing negotiation algorithms that can strike multiple partial deals with multiple partners. This requires a new type of functionality for negotiation algorithms: devising and readjusting an overall procurement plan while coordinating multiple bilateral negotiations. As such, this endeavor falls within a wider vision of what is called the 'forth industrial revolution': i.e., cyber-physical systems with autonomous machine-to-machine communication [66], of which digital purchasing is a key element.

2 KNOWLEDGE GAP

In recent years, research on automated negotiation has progressed in formalizing and automating negotiations [28, 30, 38, 39, 49], predominantly in a bilateral (one-to-one) setting (see Table 1).

Some have been extended to multiple opponents in certain settings; for example, when negotiating about a single *issue* (e.g. obtaining the cheapest price) or procuring a single *deal*, such as one art painting or one property.

Auctions are an alternative way to come to an agreement between multiple parties; however, these approaches, such as combinatorial auctions, require a *mediated* mechanism with an auctioneer, which usually does not provide scope for a familiar mode of interaction to procurement specialists; i.e. one based on a private and personal exchange of bilateral information [2]. Negotiation is also studied by game theory, but due to assumptions about full information and perfect rationality, the setting almost always reduces to a solution where no actual negotiation occurs [18]. In short: it is currently largely unknown how to negotiate multiple complex deals at the same time. In 2020, it was stated outright in [66] that lack of research in this field makes for a substantial gap in academic literature.

In fact, according to Byde et al., there were no attempts in the literature to address this type of negotiations until 2003 [18]. It was still identified as a key research problem in 2011 by Mansour and Kowalczyk, who observed that "most published work focus on the situation where agents negotiate over a single continuous issue (e.g. price) for the purpose of securing one agreement" [48]. Seven years later, in 2018, it still held true that "very little work has been done while considering interdependencies and trade-offs among multiple negotiations" [60], and in 2020, none of the research had tackled this "important open problem" in a satisfactory manner [14].

3 KEY RESEARCH CHALLENGES

The research challenges of multi-deal negotiation call for solution concepts that will make negotiation algorithms capable of aligning, combining, and engaging in multiple general-purpose negotiations at the same time. This paper focuses on three key challenges of modeling, negotiating, and coordinating multiple deals, which currently hinder major advancements in developing a general-purpose multi-deal procurement system.

As our take on tackling these research challenges, we first present our overall perspective of viewing multi-deal negotiation as an *agent coordination problem*, in which the buyer can engage in concurrent negotiations with many sellers through a bilateral exchange of offers (see Figure 2). In this view, we can delegate the negotiation task to multi-deal bilateral negotiating agents (new or existing), while the coordination between them can be done by an intelligent coordination algorithm.

3.1 Modeling challenge: developing multi-deal protocols and aggregation methods

In real-life procurement, buyers often wish to negotiate in multiple private bilateral interactions with sellers, where offers can be proposed and retracted at any time, allowing room for strategic maneuvering – for instance by offering a limited offer bundle discount. All these interactions happen concurrently, which is impossible to model with the most-used negotiation protocols as they are sequential [65]. At the same time, the interdependence between the bilateral interactions requires proper synchronization: for example, a buyer should be able to engage in multiple concurrent negotiations over a particular item without risking ending up with more than required. We know from literature that this type of research is labeled as one of the most important challenges for automated negotiation [42], in which frameworks and analysis tools for bilateral negotiations cannot be directly applied [69].

In order to negotiate effectively with multiple parties at the same time, an overarching multi-deal negotiation framework is required that allows reasoning about concurrent exchanges of bundled offers with multiple opponents and a way to evaluate deals with respect to the overall, aggregated goal of the buyer. Consequently, a first

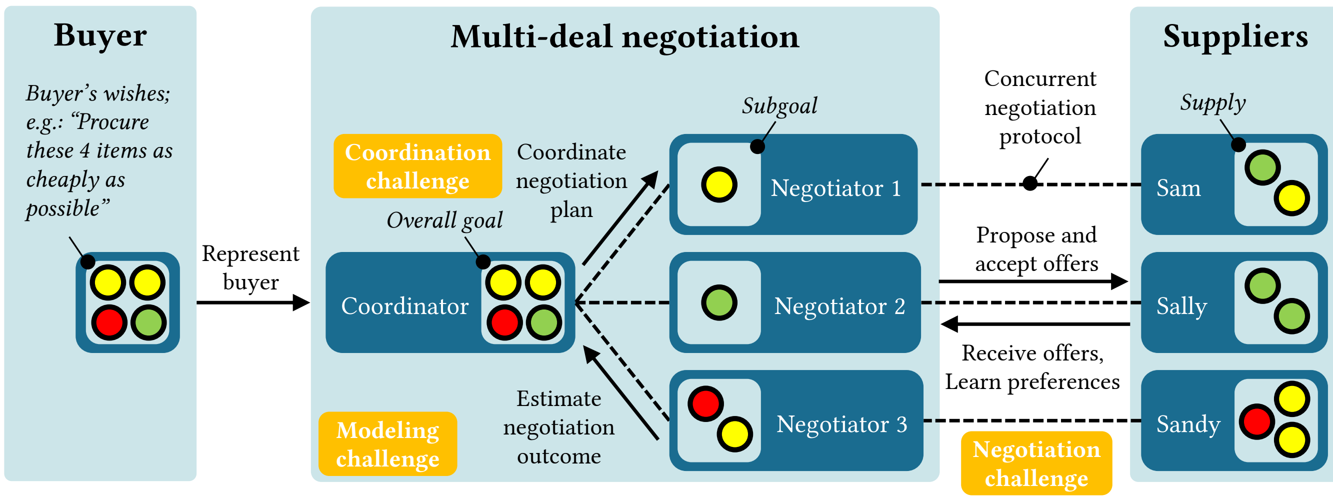


Figure 2: The overall vision for a multi-deal negotiation framework.

way forward is to define a general model for handling multi-issue bundle offers and combining them.

Currently, the most used model for making offers in single-deal negotiations is the alternating multi-issue offers protocol [65], where a negotiation is a back-and-forth offering of values in $V_1 \times \cdots \times V_m$ of negotiable issues $1, \ldots, m$. However, this protocol and many of its extensions cannot be used in the fully concurrent setting of procurement [4], because offers cannot be renewed, retracted or combined, making it impossible to adapt to changes in each ongoing interaction. We argue that in order to address these problems, we need to study new bundle-based protocols that enable concurrent agreements by allowing multiple successive overriding offers that can be aggregated and employ mechanisms like double-accept to acknowledge agreement, in line with common procurement interaction patterns that occur in practice. To formalize this notion, a good place to start could be the single-deal negotiation architecture by Rahwan [63], but this time in a multi-deal setting, in which concurrent negotiator threads are responsible for acquiring part of the overall bundle independently, aided by a coordination mechanism for passing status and coordination messages between them [7].

More formally, what is required is a protocol based on the exchange of *bundles* b, which are sets of n offers. A possible approach is to define an agent's utility function $u(b)$ on entire bundles, or even on all possible subsets of offers. This approach is sometimes used in (combinatorial) auction settings, but incompatible with existing negotiating agents that determine their utility on single, multi-issue offers. For multiple offers that are defined on the same set of issues, an alternative option is a general-purpose reduction operation on bundles, using a general *aggregation function* $a : (V_1 \times \cdots \times V_m)^2 \rightarrow V_1 \times \cdots \times V_m$. For instance, when procuring ink as in our magazine publisher example, each type of ink specifies issues such as *quantity*, *unit price*, and *delivery time* (see Figure 1); the aggregation a_i of two offers for ink of type i would be subsequent addition, weighted averaging, and maximization:

$$a_i((q,\ p,\ d), (q', p', d')) = \left(q\ +\ q',\ \frac{qp + q'p'}{q + q'}, \max\left(d,\ d'\right)\right).$$

Given appropriate choices for the domain and preferences of the agents, the analysis of new multi-deal protocols can be guided by studying multilateral protocols in previous, non-concurrent work [4] and metrics from concurrency theory (e.g. liveness, efficiency, concurrency, compatibility with former protocols). Such protocols should be able to display fully asynchronous behavior by allowing to signal interest by retracting and overwriting previous actions, while avoiding the need for special de-commitment actions used in many existing approaches [24, 59, 68]. Ideally, such an approach results in a new type of bundle-based consecutive protocol that is a generalization of both the well-known multi-issue alternating offers protocol and single deal one-to-many negotiations.

3.2 Negotiation challenge: developing bilateral strategies and outcome estimates

A second important challenge is to devise negotiation strategies that are responsible for obtaining only part of the overall requirements. Since some negotiations might not go to plan (e.g. it turns out Italy is unable to deliver red ink), each negotiator must be able to adjust their strategy dynamically to secure a deal in line with the overall plan (e.g. attempting to obtain more red ink cheaply elsewhere). Furthermore, the negotiating agent must provide continuous updates about its state to aid the coordination process, for example about what kind of agreement can be expected. A considerable hurdle is that these estimates need to be performed on-the-fly (i.e., while the negotiation, and all others, are ongoing) and under opponent uncertainty, with many unanswered questions about how this can be achieved [12, 13, 40].

Therefore, a negotiation strategy that is based on a bundle-based model needs to determine its offers carefully in light of the buyer's overall goal and provide continuous updates about the state of the negotiation, since it will strike only part of multiple bilateral agreements. This is an open challenge, but possible avenues include negotiation strategies that can provide acceptance probability estimates p_x [21, 34] about the outcomes x in the current negotiation state. These can be combined with insights from search theory [9] which indicate that given a sequence of offered bundles $(x_1, \ldots, x_k) \in \Omega^k$, it is possible to tractably specify and optimize the expected utility in a bilateral negotiation:

$$EU(x_1, \ldots, x_k) = \sum_{i=1}^{k} p_{x_i} u(x_i) \prod_{j=1}^{i-1} (1 - p_{x_j}).$$

Techniques from simultaneous search theory can help optimize EU using a greedy search strategy over the outcome space Ω, which can be done in polynomial time [20, 55]. Not only can this notion give rise to negotiation strategies that can maximize expected negotiation payoff as part of an overall procurement plan, but these algorithms can be leveraged at no extra complexity cost to include the accompanying outcome probabilities $p_{x_1^*}, \ldots, p_{x_n^*}$ of the optimal offer sequence

$$(x_1^*, \ldots, x_k^*) = \underset{x_1, \ldots, x_k}{\arg\max}\, EU(x_1, \ldots, x_k),$$

which can be computed during the search for suitable offers and can subsequently be incorporated in the coordination mechanism.

3.3 Coordination challenge: formulating aggregate multi-deal coordination strategies

A final major challenge is the decision problem of how to coordinate each negotiation, given their highly uncertain status. A considerable complication is that the same items may be obtained from multiple sellers who offer them under varying conditions (e.g. for a different price, or only as part of a bundle). As a consequence, the number of ways to split the overall requirements among the negotiators (i.e. the combinatorial problem of *what* to procure from *whom*) is enormous, with no clear way of searching through this space effectively. Formulating a procurement plan that maximizes the overall (expected) utility of the aggregated outcome is therefore a challenge of aligning bilateral negotiations and splitting them optimally towards a common goal, which was still considered challenging as recent as 2018 [60], while having received very little attention in the literature so far [17].

When aligning the bilateral negotiations as in Figure 2, it is important to ensure that the most optimal *partial* results are reached in each bilateral negotiation to maximize *overall* utility. Even when the bilateral interactions themselves are assumed given, new and scalable multi-deal coordination techniques are required that can make optimal utility trade-offs between multiple suppliers.

The most general form of the coordination problem is to reach agreements $x_1, \ldots, x_n$ with each seller, which involves optimizing the overall general bundle utility $u(\{x_1, \ldots, x_n\})$ – or an appropriate aggregation thereof, as discussed above – over the large space of all breakdowns of the buyer's wish list. One possible approach is to exploit the additive utility structure that u might display in both offers and issues, which leads to the complex but tractable problem of maximizing an arbitrarily complex linear combination of value functions over the space of all possible bundle combinations; i.e.:

$$\max_{x_1, \ldots, x_n} \sum_i \lambda_i \sum_j \mu_j v_j(x^i_{1,j}, \ldots, x^i_{n,j}).$$

Some promising results on how to achieve an efficient solution (i.e. linear in terms of sellers and quantities) for the key attributes in procurement (i.e. price and quantity), could come from insights from the field of convex optimization [7, 18]. The key idea here is that instead of looking at the intractable combinatorial space of all possible deals, we can exploit the additive structure of the utility function with careful assignment of each item per negotiator. More precisely, let $\mathbf{x} = (x_1, \ldots, x_n)$ be the coordinator's division of this item; i.e. x_i is the quantity to be obtained from seller i, who sells the item at price $p_i(x_i)$. Each seller i has at most q_i of the item to sell, and hence the solution must lie in the hyperrectangle $R = \prod_i [0, q_i]$. We can tighten this even further by sorting sellers by price and letting $\delta\mathbf{x} = (q_1, \ldots, q_d, \rho, 0, \ldots, 0)$ such that $\sum_i q_i + \rho = |\mathbf{x}|_1$ and $\rho \leq q_{d+1}$. Employing this formulation, it is easy to show that u admits its maximum on $\delta R = \{\delta\mathbf{x} \mid \mathbf{x} \in R\}$, which diminishes the search space dramatically: since there is a natural bijection between $\mathbf{x} \in \delta R$ and $|\mathbf{x}|_1$, there are only $n + \sum_i q_i$ cases to check, which is even small enough to search exhaustively. There is still work to be done, however, to refine this approach for general multi-issue utility functions, let alone non-linear functions with complex interdependencies [29, 50, 64].

4 RELEVANCE AND POTENTIAL

Although much is still unknown about concurrent, multi-deal negotiation, it is clear that the wider impact of such technology would be far-reaching. It impacts any practical scenario where, rather than engaging in a mediated mechanism such as an auction, a buyer may wish to negotiate privately and bilaterally with multiple individual sellers. In 2020, Microsoft and Ernst & Young noted the many potentially valuable use-cases of AI in procurement for at least 95% of European procurement companies [54]. Purchasing managers expect automated negotiations to become commonplace in the near future [15], impacting current procurement processes substantially [66].

The results are thus important for many critical social, technical and economical application areas around procurement and even beyond, such as trading, data, smart energy networks, privacy, transportation systems, logistics, and even ethics [5, 53, 56, 61]. In order to make further progress, ideas around multi-deal negotiation could spark a new competition league in the international Automated Negotiating Agent Competition (ANAC) [6] where participants need to design an autonomous negotiator that can broker multiple deals.

Fortunately, in recent years great strides have been made in the research area of negotiation, in part as a result of recent theoretical advances and bilateral automated negotiation competitions, yielding a better understanding of effective bilateral bidding strategies, learning methods, and acceptance strategies [8, 10, 11, 22, 41, 44, 52, 57, 73, 74]. This means essential ingredients are now available to tackle these challenges, and to take the leap into the territory of multi-deal negotiations.

ACKNOWLEDGMENTS

This publication is part of the Vidi project COMBINE (VI.Vidi.203.044) which is (partly) financed by the Dutch Research Council (NWO).

REFERENCES

[1] Bo An, Nicola Gatti, and Victor R. Lesser. 2009. Extending Alternating-Offers Bargaining in One-to-Many and Many-to-Many Settings. In *Proceedings of the*

2009 IEEE/WIC/ACM International Conference on Intelligent Agent Technology, IAT 2009, Milan, Italy, Vol. 2. 423–426. https://doi.org/10.1109/WI-IAT.2009.188

[2] Bo An, Kwang Mong Sim, Liang Gui Tang, Shuang Qing Li, and Dai Jie Cheng. 2006. Continuous-time negotiation mechanism for software agents. *IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics)* 36, 6 (2006), 1261–1272.

[3] Rebecca Angeles and Ravi Nath. 2007. Business-to-business e-procurement: success factors and challenges to implementation. *Supply Chain Management: An International Journal* (2007).

[4] Reyhan Aydoğan, David Festen, Koen V. Hindriks, and Catholijn M. Jonker. 2016. Alternating offers protocols for multilateral negotiation. In *Modern Approaches to Agent-based Complex Automated Negotiation (Studies in Computational Intelligence, Vol. 674)*. Springer International Publishing.

[5] Tim Baarslag, Alper T. Alan, Richard Gomer, Mudasser Alam, Charith Perera, Enrico H. Gerding, and M.C. Schraefel. 2017. An Automated Negotiation Agent for Permission Management. In *Proceedings of the 2017 International Conference on Autonomous Agents and Multi-agent Systems* (Sao Paulo, Brazil) *(AAMAS '17)*. International Foundation for Autonomous Agents and Multiagent Systems, Richland, SC, 380–390. http://dl.acm.org/citation.cfm?id=3091125.3091184

[6] Tim Baarslag, Reyhan Aydoğan, Koen V. Hindriks, Katsuhide Fuijita, Takayuki Ito, and Catholijn M. Jonker. 2015. The Automated Negotiating Agents Competition, 2010-2015. *AI Magazine* 36, 4 (12/2015 2015), 115–118. http://www.aaai.org/ojs/index.php/aimagazine/article/view/2609

[7] Tim Baarslag, Tijmen Elfrink, Faria Nassiri Mofakham, Thimjo Koça, Michael Kaisers, and Reyhan Aydogan. 2021. Bargaining Chips: Coordinating One-to-Many Concurrent Composite Negotiations. In *IEEE/WIC/ACM International Conference on Web Intelligence* (Melbourne, Australia) *(WI-IAT '21)*. Association for Computing Machinery, New York, NY, USA, 390–397. https://doi.org/10.1145/3486622.3494023

[8] Tim Baarslag, Katsuhide Fujita, Enrico H. Gerding, Koen V. Hindriks, Takayuki Ito, Nicholas R. Jennings, Catholijn M. Jonker, Sarit Kraus, Raz Lin, Valentin Robu, and Colin R. Williams. 2013. Evaluating practical negotiating agents: Results and analysis of the 2011 international competition. *Artificial Intelligence* 198 (May 2013), 73 – 103. https://doi.org/10.1016/j.artint.2012.09.004

[9] Tim Baarslag, Enrico H. Gerding, Reyhan Aydoğan, and M.C. Schraefel. 2015. Optimal Negotiation Decision Functions in Time-Sensitive Domains. In *2015 IEEE/WIC/ACM International Joint Conferences on Web Intelligence (WI) and Intelligent Agent Technologies (IAT)*, Vol. 2. 190–197. https://doi.org/10.1109/WI-IAT.2015.161

[10] Tim Baarslag, Koen V. Hindriks, Mark J.C. Hendrikx, Alex S.Y. Dirkzwager, and Catholijn M. Jonker. 2014. Decoupling Negotiating Agents to Explore the Space of Negotiation Strategies. In *Novel Insights in Agent-based Complex Automated Negotiation*, Ivan Marsa-Maestre, Miguel A. Lopez-Carmona, Takayuki Ito, Minjie Zhang, Quan Bai, and Katsuhide Fujita (Eds.). Studies in Computational Intelligence, Vol. 535. Springer, Japan, 61–83. https://doi.org/10.1007/978-4-431-54758-7_4

[11] Tim Baarslag, Koen V. Hindriks, Catholijn M. Jonker, Sarit Kraus, and Raz Lin. 2012. The First Automated Negotiating Agents Competition (ANAC 2010). In *New Trends in Agent-based Complex Automated Negotiations (Studies in Computational Intelligence, Vol. 383)*, Takayuki Ito, Minjie Zhang, Valentin Robu, Shaheen Fatima, and Tokuro Matsuo (Eds.). Springer-Verlag, Berlin, Heidelberg, 113–135. https://doi.org/10.1007/978-3-642-24696-8_7

[12] Tim Baarslag, Michael Kaisers, Enrico H. Gerding, Catholijn M. Jonker, and Jonathan Gratch. 2017. *Computers That Negotiate on Our Behalf: Major Challenges for Self-sufficient, Self-directed, and Interdependent Negotiating Agents*. Lecture Notes in Computer Science, Vol. 10643. Springer International Publishing, Cham, 143–163. https://doi.org/10.1007/978-3-319-71679-4_10

[13] Tim Baarslag, Michael Kaisers, Enrico H. Gerding, Catholijn M. Jonker, and Jonathan Gratch. 2017. When will negotiation agents be able to represent us? The challenges and opportunities for autonomous negotiators. In *Proceedings of the Twenty-sixth International Joint Conference on Artificial Intelligence* (Melbourne, Australia) *(IJCAI'17)*. 4684–4690. https://doi.org/10.24963/ijcai.2017/653

[14] Pallavi Bagga, Nicola Paoletti, Bedour Alrayes, and Kostas Stathis. 2020. A Deep Reinforcement Learning Approach to Concurrent Bilateral Negotiation. *arXiv preprint arXiv:2001.11785* (2020).

[15] R Bogaschewsky and H Müller. 2018. BME-Barometer Elektronische Beschaffung. *Bundesverband Materialwirtschaft, Einkauf und Logistik eV* (2018).

[16] Frances M.T. Brazier, Frank Cornelissen, Rune Gustavsson, Catholijn M. Jonker, Olle Lindeberg, Bianca Polak, and Jan Treur. 2002. A multi-agent system performing one-to-many negotiation for load balancing of electricity use. *Electronic Commerce Research and Applications* 1, 2 (2002), 208 – 224. https://doi.org/10.1016/S1567-4223(02)00013-3

[17] Jakub Brzostowski and Ryszard Kowalczyk. 2007. On Fuzzy Projection-Based Utility Decomposition in Compound Multi-agent Negotiations. In *Foundations of Fuzzy Logic and Soft Computing*, Patricia Melin, Oscar Castillo, Luis T. Aguilar, Janusz Kacprzyk, and Witold Pedrycz (Eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 757–766.

[18] Andrew Byde, Michael Yearworth, Kay-Yut Chen, and Claudio Bartolini. 2003. AutONA: A system for automated multiple 1-1 negotiation. In *EEE International Conference on E-Commerce, 2003. CEC 2003.* IEEE, 59–67.

[19] Sofia Ceppi and Nicola Gatti. 2010. An algorithmic game theory framework for bilateral bargaining with uncertainty. In *Proceedings of the 9th International Conference on Autonomous Agents and Multiagent Systems: volume 1-Volume 1*. 1489–1490.

[20] Hector Chade and Lones Smith. 2006. Simultaneous Search. *Econometrica* 74, 5 (2006), 1293–1307. https://doi.org/10.1111/j.1468-0262.2006.00705.x

[21] Siqi Chen, Jianye Hao, Gerhard Weiss, Karl Tuyls, and Ho-fung Leung. 2014. Evaluating practical automated negotiation based on spatial evolutionary game theory. In *KI 2014: Advances in Artificial Intelligence*, Carsten Lutz and Michael Thielscher (Eds.). Lecture Notes in Computer Science, Vol. 8736. Springer International Publishing, 147–158. https://doi.org/10.1007/978-3-319-11206-0_15

[22] Siqi Chen, Jianye Hao, Shuang Zhou, and Gerhard Weiss. 2017. *Negotiating with Unknown Opponents Toward Multi-lateral Agreement in Real-Time Domains*. Springer International Publishing, Cham, 219–229. https://doi.org/10.1007/978-3-319-51563-2_17

[23] Siqi Chen and Gerhard Weiss. 2014. OMAC: A Discrete Wavelet Transformation Based Negotiation Agent. In *Novel Insights in Agent-based Complex Automated Negotiation*, Ivan Marsa-Maestre, Miguel A. Lopez-Carmona, Takayuki Ito, Minjie Zhang, Quan Bai, and Katsuhide Fujita (Eds.). Studies in Computational Intelligence, Vol. 535. Springer Japan, 187–196. https://doi.org/10.1007/978-4-431-54758-7_13

[24] Jiangbo Dang and Michael N Huhns. 2005. An extended protocol for multiple-issue concurrent negotiation. In *Proceedings of the National Conference on Artificial Intelligence*, Vol. 20. Menlo Park, CA, 65.

[25] Peyman Faratin, Carles Sierra, and Nicholas R. Jennings. 1998. Negotiation decision functions for autonomous agents. *Robotics and Autonomous Systems* 24, 3-4 (1998), 159 – 182. https://doi.org/10.1016/S0921-8890(98)00029-3

[26] Shaheen S Fatima, Michael Wooldridge, and Nicholas R Jennings. 2005. Bargaining with incomplete information. *Annals of Mathematics and Artificial Intelligence* 44, 3 (2005), 207–232.

[27] Shaheen S. Fatima, Michael J. Wooldridge, and Nicholas R. Jennings. 2002. Multi-issue negotiation under time constraints. In *AAMAS '02: Proceedings of the first international joint conference on Autonomous agents and multiagent systems* (Bologna, Italy). ACM, New York, NY, USA, 143–150. https://doi.org/10.1145/544741.544775

[28] Katsuhide Fujita, Quan Bai, Takayuki Ito, Minjie Zhang, Fenghui Ren, Reyhan Aydoğan, and Rafik Hadfi. 2017. *Modern approaches to agent-based complex automated negotiation*. Springer.

[29] Katsuhide Fujita, Takayuki Ito, and Mark Klein. 2014. Efficient issue-grouping approach for multiple interdependent issues negotiation between exaggerator agents. *Decision Support Systems* 60 (2014), 10–17. https://doi.org/10.1016/j.dss.2013.05.016 Automated Negotiation Technologies and their Applications.

[30] Naoki Fukuta, Takayuki Ito, Minjie Zhang, Katsuhide Fujita, and Valentin Robu. 2016. *Recent Advances in Agent-based Complex Automated Negotiation*. Vol. 638. Springer.

[31] Ya'akov Gal, Barbara J. Grosz, Sarit Kraus, Avi Pfeffer, and Stuart Shieber. 2005. Colored trails: a formalism for investigating decision-making in strategic environments. In *Proceedings of the 2005 IJCAI workshop on reasoning, representation, and learning in computer games*. 25–30.

[32] Enrico Harm Gerding. 2004. *Autonomous agents in bargaining games: an evolutionary investigation of fundamentals, strategies, and business applications*. Ph.D. Dissertation. Technische Universiteit Eindhoven.

[33] Jonathan Gratch, Zahra Nazari, and Emmanuel Johnson. 2016. The Misrepresentation Game: How to Win at Negotiation While Seeming Like a Nice Guy. In *Proceedings of the 2016 International Conference on Autonomous Agents and Multiagent Systems* (Singapore, Singapore) *(AAMAS '16)*. International Foundation for Autonomous Agents and Multiagent Systems, Richland, SC, 728–737. http://dl.acm.org/citation.cfm?id=2936924.2937031

[34] Jianye Hao and Ho-fung Leung. 2014. CUHKAgent: An Adaptive Negotiation Strategy for Bilateral Negotiations over Multiple Items. In *Novel Insights in Agent-based Complex Automated Negotiation*, Ivan Marsa-Maestre, Miguel A. Lopez-Carmona, Takayuki Ito, Minjie Zhang, Quan Bai, and Katsuhide Fujita (Eds.). Studies in Computational Intelligence, Vol. 535. Springer Japan, 171–179. https://doi.org/10.1007/978-4-431-54758-7_11

[35] Takayuki Ito, Hiromitsu Hattori, and Mark Klein. 2007. Multi-issue negotiation protocol for agents: exploring nonlinear utility spaces. In *Proceedings of the 20th international joint conference on artifical intelligence* (Hyderabad, India) *(IJCAI'07)*. Morgan Kaufmann Publishers Inc., San Francisco, CA, USA, 1347–1352. http://dl.acm.org/citation.cfm?id=1625275.1625493

[36] Takayuki Ito and Mark Klein. 2006. A Multi-Issue Negotiation Protocol among Competitive Agents and Its Extension to a Nonlinear Utility Negotiation Protocol. In *Proceedings of the Fifth International Joint Conference on Autonomous Agents and Multiagent Systems* (Hakodate, Japan) *(AAMAS '06)*. Association for Computing Machinery, New York, NY, USA, 435–437. https://doi.org/10.1145/1160633.1160713

[37] Takayuki Ito, Mark Klein, and Hiromitsu Hattori. 2008. A multi-issue negotiation protocol among agents with nonlinear utility functions. *Multiagent and Grid Systems* 4, 1 (Jan 2008), 67–83. http://dl.acm.org/citation.cfm?id=1378675.1378678

[38] Takayuki Ito, Minjie Zhang, Valentin Robu, Shaheen Fatima, and Tokuro Matsuo. 2011. New Trends in Agent-Based Complex Automated Negotiations. (2011).

[39] Takayuki Ito, Minjie Zhang, Valentin Robu, and Tokuro Matsuo. 2013. *Complex automated negotiations: Theories, models, and software competitions.* Springer.

[40] Vicente Julian, Victor Sanchez-Anguix, Stella Heras, and Carlos Carrascosa. 2020. Agreement Technologies for Conflict Resolution. In *Natural Language Processing: Concepts, Methodologies, Tools, and Applications.* IGI Global, 464–484.

[41] Shinji Kakimoto and Katsuhide Fujita. 2017. *Compromising Strategy Considering Interdependencies of Issues for Multi-issue Closed Nonlinear Negotiations.* Springer International Publishing, Cham, 85–100. https://doi.org/10.1007/978-3-319-51563-2_6

[42] Ryohei Kawata and Katsuhide Fujita. 2020. Cooperativeness Measure Based on the Hypervolume Indicator and Matching Method for Concurrent Negotiations. In *Advances in Automated Negotiations*, Takayuki Ito, Minjie Zhang, and Reyhan Aydoğan (Eds.). Springer Singapore, Singapore, 117–135.

[43] Sarit Kraus, Jonathan Wilkenfeld, and Gilad Zlotkin. 1995. Multiagent negotiation under time constraints. *Artificial Intelligence* 75, 2 (1995), 297 – 345. https://doi.org/DOI:10.1016/0004-3702(94)00021-R

[44] Max W. Y. Lam and Ho-fung Leung. 2017. *Phoenix: A Threshold Function Based Negotiation Strategy Using Gaussian Process Regression and Distance-Based Pareto Frontier Approximation.* Springer International Publishing, Cham, 201–212. https://doi.org/10.1007/978-3-319-51563-2_15

[45] Cuihong Li, Joseph Giampapa, and Katia P. Sycara. 2006. Bilateral negotiation decisions with uncertain dynamic outside options. *IEEE Transactions on Systems, Man, and Cybernetics, Part C: Applications and Reviews* 36, 1 (Jan 2006), 31–44. https://doi.org/10.1109/TSMCC.2005.860573

[46] Raz Lin, Sarit Kraus, Jonathan Wilkenfeld, and James Barry. 2008. Negotiating with bounded rational agents in environments with incomplete information using an automated agent. *Artificial Intelligence* 172, 6-7 (2008), 823 – 851. https://doi.org/DOI:10.1016/j.artint.2007.09.007

[47] Miguel A Lopez-Carmona, Ivan Marsa-Maestre, Juan R Velasco, and Enrique de la Hoz. 2010. A multi-issue negotiation framework for non-monotonic preference spaces. In *Proceedings of the 9th International Conference on Autonomous Agents and Multiagent Systems: volume 1-Volume 1.* International Foundation for Autonomous Agents and Multiagent Systems, 1611–1612.

[48] Khalid Mansour and Ryszard Kowalczyk. 2011. A meta-strategy for coordinating of one-to-many negotiation over multiple issues. In *Foundations of Intelligent Systems.* Springer, 343–353.

[49] Ivan Marsa-Maestre, Miguel A Lopez-Carmona, Takayuki Ito, Minjie Zhang, Quan Bai, and Katsuhide Fujita. 2014. *Novel insights in agent-based complex automated negotiation.* Vol. 535. Springer.

[50] Ivan Marsa-Maestre, Miguel A. Lopez-Carmona, Mark Klein, Takayuki Ito, and Katsuhide Fujita. 2014. Addressing utility space complexity in negotiations involving highly uncorrelated, constraint-based utility spaces. *Computational Intelligence* 30, 1 (2014), 1–29. https://doi.org/10.1111/j.1467-8640.2012.00461.x arXiv:https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1467-8640.2012.00461.x

[51] Ivan Marsa-Maestre, Miguel A. Lopez-Carmona, Juan R. Velasco, Takayuki Ito, Mark Klein, and Katsuhide Fujita. 2009. Balancing Utility and Deal Probability for Auction-based Negotiations in Highly Nonlinear Utility Spaces. In *Proceedings of the 21st international joint conference on artificial intelligence* (Pasadena, California, USA) *(IJCAI'09).* Morgan Kaufmann Publishers Inc., 214–219.

[52] Johnathan Mell, Jonathan Gratch, Tim Baarslag, Reyhan Aydoğan, and Catholijn M. Jonker. 2018. Results of the First Annual Human-Agent League of the Automated Negotiating Agents Competition. In *Proceedings of the 18th International Conference on Intelligent Virtual Agents* (Sydney, NSW, Australia) *(IVA '18).* Association for Computing Machinery, New York, NY, USA, 23–28. https://doi.org/10.1145/3267851.3267907

[53] Mashal Afzal Memon, Gian Luca Scoccia, Paola Inverardi, and Marco Autili. 2023. Don't You Agree with My Ethics? Let's Negotiate! In *HHAI 2023: Augmenting Human Intellect.* IOS Press, 385–388.

[54] Microsoft and Ernst & Young. 2020. *Artificial Intelligence in Europe: Outlook for 2019 and Beyond.* Technical Report.

[55] Yasser Mohammad and Shinji Nakadai. 2018. FastVOI: Efficient Utility Elicitation During Negotiations. In *International Conference on Principles and Practice of Multi-Agent Systems.* Springer, 560–567.

[56] Yasser Mohammad, Enrique Areyan Viqueira, Nahum Alvarez Ayerza, Amy Greenwald, Shinji Nakadai, and Satoshi Morinaga. 2019. Supply Chain Management World. In *PRIMA 2019: Principles and Practice of Multi-Agent Systems*, Matteo Baldoni, Mehdi Dastani, Beishui Liao, Yuko Sakurai, and Rym Zalila Wenkstern (Eds.). Springer International Publishing, Cham, 153–169.

[57] Akiyuki Mori and Takayuki Ito. 2017. *Atlas3: A Negotiating Agent Based on Expecting Lower Limit of Concession Function.* Springer International Publishing, Cham, 169–173. https://doi.org/10.1007/978-3-319-51563-2_11

[58] Thuc Duong Nguyen and Nicholas R. Jennings. 2003. A heuristic model of concurrent bi-lateral negotiations in incomplete information settings. In *International Joint Conferences on Artificial Intelligence.* 1467–1469. http://eprints.soton.ac.uk/257433/

[59] Thuc Duong Nguyen and Nicholas R Jennings. 2005. Managing commitments in multiple concurrent negotiations. *Electronic Commerce Research and Applications* 4, 4 (2005), 362–376.

[60] Lei Niu, Fenghui Ren, and Minjie Zhang. 2018. Feasible Negotiation Procedures for Multiple Interdependent Negotiations. In *Proceedings of the 17th International Conference on Autonomous Agents and MultiAgent Systems* (Stockholm, Sweden) *(AAMAS '18).* International Foundation for Autonomous Agents and Multiagent Systems, Richland, SC, 641–649.

[61] Charith Perera, Susan Y. L. Wakenshaw, Tim Baarslag, Hamed Haddadi, Arosha K. Bandara, Richard Mortier, Andy Crabtree, Irene C. L. Ng, Derek McAuley, and Jon Crowcroft. 2017. Valorising the IoT Databox: creating value for everyone. *Transactions on Emerging Telecommunications Technologies* 28, 1 (2017), 1–17. https://doi.org/10.1002/ett.3125

[62] William D Presutti Jr. 2003. Supply management and e-procurement: creating value added in the supply chain. *Industrial marketing management* 32, 3 (2003), 219–226.

[63] Iyad Rahwan, Ryszard Kowalczyk, and Ha Hai Pham. 2002. Intelligent Agents for Automated One-to-many e-Commerce Negotiation. *Australian Computer Science Communications* 24, 1 (Jan 2002), 197–204. https://doi.org/10.1145/563857.563824

[64] Valentin Robu, Koye Somefun, and Johannes A. La Poutré. 2005. Modeling Complex Multi-issue Negotiations Using Utility Graphs. In *Proceedings of the Fourth International Joint Conference on Autonomous Agents and Multiagent Systems* (The Netherlands) *(AAMAS '05).* ACM, New York, NY, USA, 280–287. https://doi.org/10.1145/1082473.1082516

[65] Ariel Rubinstein. 1982. Perfect Equilibrium in a Bargaining Model. *Econometrica* 50, 1 (1982), 97–109. http://www.jstor.org/stable/1912531

[66] Holger Schiele and Robbert-Jan Torn. 2020. Cyber-physical systems with autonomous machine-to-machine communication: Industry 4.0 and its particular potential for purchasing and supply management. *International Journal of Procurement Management* 13, 4 (2020), 507–530.

[67] Kwang Mong Sim. 2013. Complex and Concurrent Negotiations for Multiple Interrelated e-Markets. *IEEE Transactions on Cybernetics* 43, 1 (Feb 2013), 230–245. https://doi.org/10.1109/TSMCB.2012.2204742

[68] Kwang Mong Sim and Benyun Shi. 2010. Concurrent negotiation and coordination for grid resource coallocation. *IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics)* 40, 3 (2010), 753–766.

[69] Yoshinori Tsuruhashi and Naoki Fukuta. 2013. A Framework for Analyzing Simultaneous Negotiations. In *PRIMA 2013: Principles and Practice of Multi-Agent Systems*, Guido Boella, Edith Elkind, Bastin Tony Roy Savarimuthu, Frank Dignum, and Martin K. Purvis (Eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 526–533.

[70] Colin R. Williams, Valentin Robu, Enrico H. Gerding, and Nicholas R. Jennings. 2012. Negotiating Concurrently with Unknown Opponents in Complex, Real-Time Domains. In *20th European Conference on Artificial Intelligence*, Vol. 242. 834–839. http://eprints.soton.ac.uk/339064/

[71] Colin R. Williams, Valentin Robu, Enrico H. Gerding, and Nicholas R. Jennings. 2012. Towards a Platform for Concurrent Negotiations in Complex Domain. In *Proceedings of The Fifth International Workshop on Agent-based Complex Automated Negotiations (ACAN 2012).*

[72] ShiKui Wu and Gregory E Kersten. 2017. Procurement auctions and negotiations: An empirical comparison. *Journal of Organizational Computing and Electronic Commerce* 27, 4 (2017), 281–303.

[73] Osman Yucel, Jon Hoffman, and Sandip Sen. 2017. *Jonny Black: A Mediating Approach to Multilateral Negotiations.* Springer International Publishing, Cham, 231–238. https://doi.org/10.1007/978-3-319-51563-2_18

[74] Farhad Zafari and Faria Nassiri-Mofakham. 2016. *Recent Advances in Agent-based Complex Automated Negotiation.* Springer International Publishing, Cham, Chapter BraveCat: Iterative Deepening Distance-Based Opponent Modeling and Hybrid Bidding in Nonlinear Ultra Large Bilateral Multi Issue Negotiation Domains, 285–293. https://doi.org/10.1007/978-3-319-30307-9_21

[75] Dajun Zeng and Katia P. Sycara. 1998. Bayesian learning in negotiation. *International Journal of Human-Computer Studies* 48, 1 (1998), 125 – 141. https://doi.org/10.1006/ijhc.1997.0164